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THE EFFECT OF VIEWING TIME, TIME TO ENCOUNTER, AND PRACTICE ON PERCEPTION OF AIRCRAFT SEPARATION ON A COCKPIT DISPLAY OF TRAFFIC INFORMATION

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SUMMARY

The concept of a cockpit display of traffic information (CDTI) includes the integration of air traffic, navigation, and other pertinent information in a single electronic display in the cockpit. The two studies reported here were conducted as part of a research project designed to develop a clear and concise display format for use in later full-mission simulator evaluations of the CDTI concept. Subjects were required to monitor a CDTI for specified periods of time and to make perceptual judgments concerning the future position of a single intruder aircraft in relationship to their own aircraft. Experimental variables included: type of predictor information displayed on the two aircraft symbols; time to encounter point; length of time subjects viewed the display; amount of practice; and type of encounter (straight or turning). Results show that length of viewing time had little or no effect on performance; time to encounter influenced performance with the straight predictor but did not with the curved predictor; and that learning occurred under all conditions.

INTRODUCTION

It has become increasingly important that new solutions to the problem of maintaining safe aircraft separation in dense air traffic be found. Although the concept of displaying pertinent air traffic information in the cockpit was proposed several years ago, it has only recently been seriously considered. One proposed method of achieving a cockpit display of traffic information (CDTI) in future aircraft is to add traffic information to the pilot's electronic navigation and map display. The position of one's aircraft (hereafter referred to as own-ship) and the direction of travel with respect to area navigation routes and terrain features would be indicated by a trackup moving map display. The display computer would continually translate and rotate this map so that current aircraft location would be represented by a fixed aircraft symbol. Objects on the display would move down the display at a rate proportional to aircraft movement over the ground. When own-ship turns, all objects on the map rotate about the fixed aircraft symbols. Symbols

*This work was performed under Grant NSG 2269 while at San Jose State University; presently San Francisco State University.

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showing the location of other air traffic would move with respect to both ground-referenced objects and to own-ship.

Four prior experiments in this project were directed toward developing a clear and easy-to-use generic CDTI display (ref. 1). Questions concerning the generic CDTI display were directed toward the display symbology and factors affecting perception of motion. Of major concern were alternative methods of displaying past and future position of the aircraft (history and predictor types). Results of these four experiments indicated (1) that best performance was achieved with predictors that included turn-rate information, (2) that encounters involving turning aircraft were perceptually more difficult, and (3) that such variables as time to encounter point, viewing time, and practice may influence accuracy. The two experiments presented in this paper parallel the previous research; they are referred to as Experiments 5 and 6 to continue the numerical sequence. Experiments 5 and 6 were concerned primarily with viewing time, time to point of encounter, practice effects, and response perseverance.

Subjects were asked to make judgments, while monitoring a dynamic CDTI display, concerning the future separation between their own aircraft and an intruder aircraft. The number of errors was recorded to determine the accuracy of their judgments.

METHOD

Display Hardware

The CDTI was displayed on an 18- by 18-cm (7- by 7-in.) cathode ray tube (CRT) located directly below the attitude indicator in a fixed-base cockpit simulator. The center of the display was 25° (0.44 rad) below the horizontal and 0.87 m (2.85 ft) from the subject's eye reference point. The display elements were generated by a general purpose stroke-writing computer graphics system.

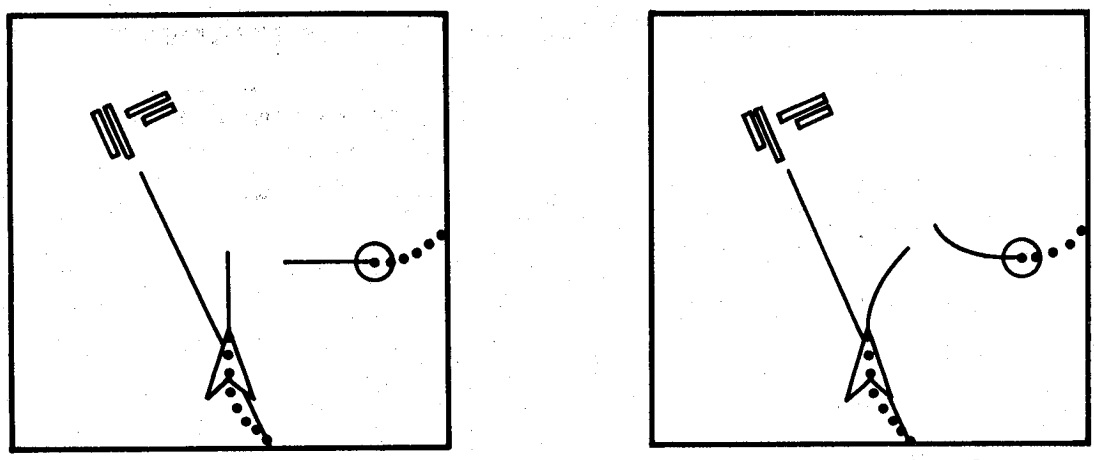
Display Symbology

The two display formats in these experiments utilized either straight or curved predictors (see fig. 1). The following display elements were not changed in these experiments:

1. Present position of own-ship was always indicated by a chevron symbol; the top point of this symbol indicated the actual location of own-ship.

2. Present position of the intruder was indicated by a dot in the center of a circular symbol; these symbols were preferred by most pilots in Hart's study (ref. 2).

3. RNAV (area navigation route map) route and runway symbols provided ground objects for background.



(a) Straight ground reference. (b) Curved ground reference.

Figure 1.- Straight and curved ground-referenced predictors for an encounter.

4. The width of the terrain displayed on the map was always 10 n.mi.; with this map scale, which seems reasonable for terminal area operations, 1 n. mi. on the ground equals 1.2 cm (0.5 in.) on the display. 7in/10n.mi.

5. The display was oriented with own-ship's track up.

6. Track was updated every 0.1 sec.

7. The position of own-ship and all intruder information were updated every 4 sec.

8. Ground-referenced history, the past flightpath of the aircraft over the ground, was represented by a "dropped" dot every 4 sec.

No sensor noise or tracker lag was simulated for any of these tests.

The independent display variables included: (1) viewing time; (2) time to encounter; (3) type of encounter (straight or turning); (4) type of predictor on own-ship and intruder; and (5) amount of practice. Table 1 shows the various combinations of display variables; a more detailed description is included in the discussion of the individual experiments.

Encounter Variables

Figure 2 shows the eight parameters that were used to specify an encounter between own-ship and an intruder. In these experiments R — the separation at the point of encounter, — was 0.91 km (3,000 ft). Update of the map and the intruder was every 4 sec. Rotation of the map display about ownship was continuous. Speed, turn rate, and direction of turn of each aircraft remained unchanged from the beginning of each encounter to its conclusion. There were no encounters that would result in a collision. For each display condition, the subjects monitored 24 different encounter situations. In 12 of those encounters, the intruder would ultimately pass in front of own-ship.

TABLE 1.- PARAMETERS OF VARIABLES USED IN EXPERIMENTS 5 AND 6

	Experiment No.	
	5	6
Predictor: own-ship and intruder		
Straight[a]		X
Curved[b]	X	X
Viewing time[c]		
1 sec	X	
2 sec	X	
4 sec	X	X
8 sec	X	X
16 sec		X
Time to encounter[d]		
52 sec	X	X
48 sec		X
44 sec	X	X

[a]The end of the vector predicts the position of the aircraft over the ground in 32 sec, assuming the aircraft maintains its current track angle.

[b]The end of the vector predicts the position of the aircraft over the ground in 32 sec, assuming the aircraft maintains its current turn rate.

[c]Amount of time available for viewing the encounter situation.

[d]Time at which judgment was requested, measured so that the intruder will be either directly in front of or behind own-ship at 0 sec.

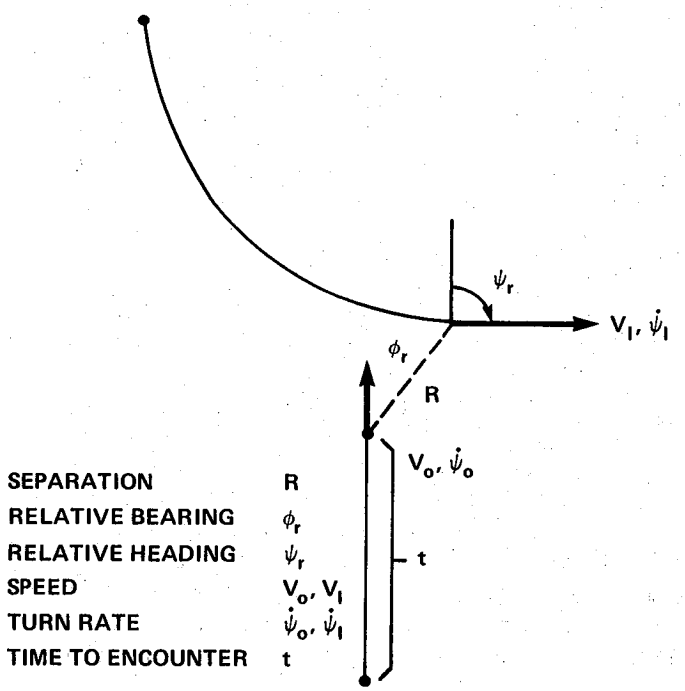


Figure 2.- Parameters used to specify an encounter between own-ship and an intruder aircraft.

Figure 3 depicts those 12 encounters and their parameters as they would appear using the curved ground-referenced predictor and history. The other 12 encounters were the same, except that the intruder aircraft would ultimately pass behind own-ship. Note that in 12 encounters both aircraft are going straight and in the remaining 12, one or both aircraft are turning. During the experiment, the order of presentation of the 24 encounters were randomized. In addition, the presentation to the subjects of either the encounters shown in figure 3 or their mirror images was also randomized.

Task

The subject's task was to monitor the CDTI display and predict whether an intruder aircraft would pass in front of or behind own-ship. Each trial was initiated by the subject pushing a start button. After two display updates (4 sec apart) the intruder appeared on the CDTI with a position, velocity, track angle, and turn rate calculated so that it would be either directly in front of or in back of own-ship at the time of encounter. As defined here, the encounter point is not necessarily the point of closest approach. After the subject viewed a given CDTI display for a specified period of time, the display was blanked and replaced by a message that asked whether the intruder aircraft would pass in front of or behind own-ship. The subject indicated his decision by pushing a hand-held switch (forward for "in front" or back for "in back"). The words IN FRONT or IN BACK then appeared as appropriate to indicating the correct judgment.

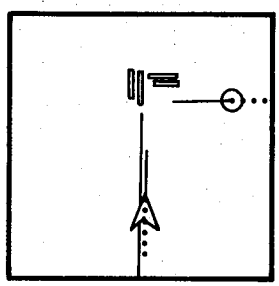
Subjects

Fourteen male students served as paid subjects in these experiments. Approximately 1 hr was spent describing the task and training test subjects to interpret the different display symbols. Before each test session, the display symbols were reviewed.

EXPERIMENT 5

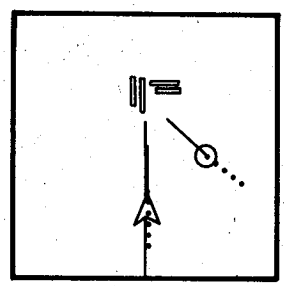
Objectives

The primary objective of Experiment 5 was to determine the effect of length of viewing time on the subjects ability to correctly perceive an encounter situation. A 16-sec viewing time was used in the previous four experiments of this project. (Experiments 1 to 4 were reported in ref. 1.) A question arose as to the minimum time required for accurate judgment. In actual in-flight encounters, pilots must interpret a display quickly and accurately. The secondary objective of interest in this study was the effect of time to encounter point. Encounters were terminated at either 44, 48, or 52 sec before encounter to determine if different times to encounter point effected the accuracy of perceptual judgments.



1

ψ_r = -90°
V_I = 200 knots
$\dot{\psi}_0$ = 0°/sec
$\dot{\psi}_I$ = 0°/sec



3

ψ_r = -45°
V_I = 200 knots
$\dot{\psi}_0$ = 0°/sec
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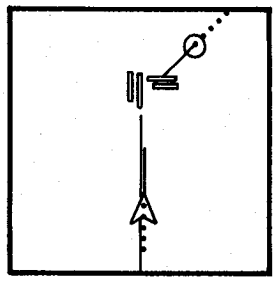
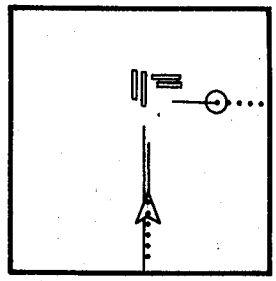


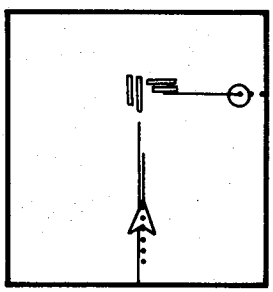
5

ψ_r = -135°
V_I = 200 knots
$\dot{\psi}_0$ = 0°/sec
$\dot{\psi}_I$ = 0°/sec



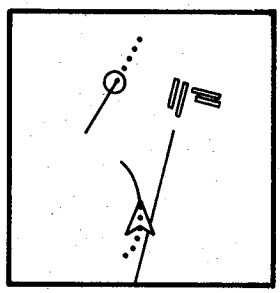
7

ψ_r = -90°
V_I = 133 knots
$\dot{\psi}_0$ = 0°/sec
$\dot{\psi}_I$ = 0°/sec



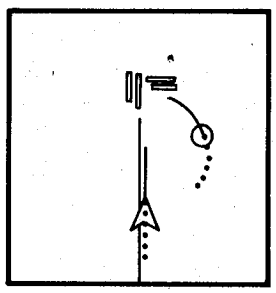
9

ψ_r = -90°
V_I = 300 knots
$\dot{\psi}_0$ = 0°/sec
$\dot{\psi}_I$ = 0°/sec



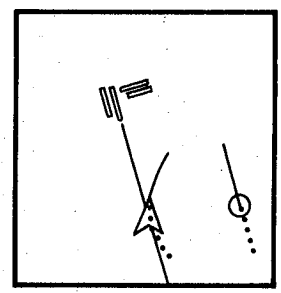
11

ψ_r = -90°
V_I = 200 knots
$\dot{\psi}_0$ = -1.50°/sec
$\dot{\psi}_I$ = 0°/sec



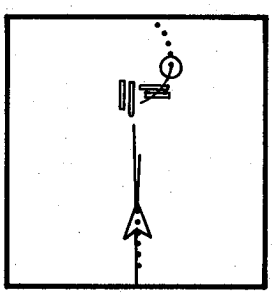
13

ψ_r = -90°
V_I = 200 knots
$\dot{\psi}_0$ = 0°/sec
$\dot{\psi}_I$ = -1.50°/sec



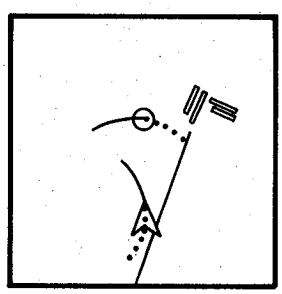
15

ψ_r = -90°
V_I = 200 knots
$\dot{\psi}_0$ = +1.50°/sec
$\dot{\psi}_I$ = 0°/sec



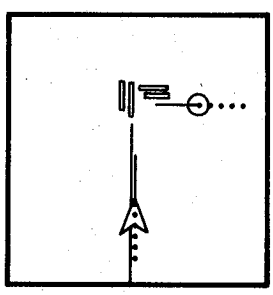
17

ψ_r = -90°
V_I = 200 knots
$\dot{\psi}_0$ = 0°/sec
$\dot{\psi}_I$ = +1.50°/sec



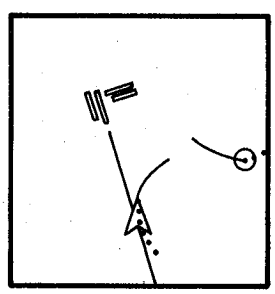
19

ψ_r = -90°
V_I = 200 knots
$\dot{\psi}_0$ = -1.50°/sec
$\dot{\psi}_I$ = -1.50°/sec



21

ψ_r = -90°
V_I = 167 knots
$\dot{\psi}_0$ = 0°/sec
$\dot{\psi}_I$ = 0°/sec



23

ψ_r = -90°
V_I = 200 knots
$\dot{\psi}_0$ = +1.50°/sec
$\dot{\psi}_I$ = +1.50°/sec

Figure 3.- Twelve of the 24 encounters in which the intruder passed in front of own-ship.

Independent Variables

The display presented in Experiment 5 utilized curved ground-referenced predictors and ground-referenced history. The curved predictor showed where an aircraft would be in 32 sec, relative to the ground, assuming the aircraft maintained its constant speed and turn rate. The magnitude of the miss distance was held constant at 0.91 km (3,000 ft).

Within each experimental trial, viewing time and time to point of encounter were varied. Baseline data and training began at 60 sec and ended at 44 sec before encounter, with a 16-sec viewing time. Test trials terminated either 44 or 52 sec before encounter and were presented for 1, 2, 4, or 8 sec (see table 2).

TABLE 2.- PERCENT ERROR AVERAGED OVER SUBJECTS WITH 24 TRIALS PER CELL PER SUBJECT FOR A TOTAL OF 144 TRIALS. TON, THE TIME TO ENCOUNTER AT START OF TRIAL EQUALED TOFF PLUS THE VIEWING TIME

TOFF, sec	Viewing time, sec			
	8	4	2	1
52	19	20	20	19
44	8	10	11	10

Experimental Design

Using the same display format, each of six subjects made judgments for both display termination times (either 44 or 52 sec before encounter), and for all viewing times (1, 2, 4, or 8 sec). Mean error rates were collected. Time to encounter, viewing time, and encounter sequence were randomized within each block of 24 runs.

Results

Table 2 shows the percent error for each viewing time and time to encounter (TOFF: time to encounter at termination). The data were averaged over subjects. In comparing the percent error it is evident that the greater the time to encounter the more difficult it was for the subjects to make accurate judgments. This is consistent with the finds of previous studies using pilots as subjects.

An ANOVA on error rate indicated a significant difference between the two times to encounter, ($F(1,2) = 35.319$, $p < 0.01$). No significant difference was found for viewing time or for any of the interactions (see table 3).

TABLE 3.- ANOVA FOR VIEWING TIME (A), TIME TO ENCOUNTER POINT (B), AND ENCOUNTER TYPE (C)

Source	SS	df	MS	F
A	0.62	3	0.21	<1
B	33.84	1	33.84	65.08[a]
C	.01	1	.01	<1
S	111.93	5	22.39	
AXS	23.19	15	1.55	
BXS	2.60	5	.52	
CXS	1.68	5	.34	
AXC	6.11	3	2.04	1.66
AXCXS	18.45	15	1.23	
AXBXC	1.86	3	.62	1.02
AXBXCXS	9.21	15	.61	

Note: Table includes main effects, significant interaction, and error terms only.
[a] $p < 0.001$

EXPERIMENT 6

Objectives

The primary objective of Experiment 6 was to further investigate the effect of decreased viewing time by extending the range of values used in Experiment 5 for time to encounter to see if the resulting performance interacted with predictor type.

A secondary objective was to test for the possibility of an effect known as response perseverance (ref. 3). When an intruder first appears, subjects may make an early judgment as to the final outcome of the encounter (the intruder passing either in front of or behind own-ship). As the data are updated and the aircraft move closer to each other, the new information is more accurate because the distance extrapolated is less. If response perseverance is present, the subject may persevere with his original decision even though the updated display would permit a more accurate decision. If response perseverance effects are present, those encounters beginning with more time to the encounter point should, despite longer viewing times, show a higher error rates than encounters beginning with less time before encounter. Subjects were tested on trials that terminated at the same time before the encounter point but which initially began at different times. For example, two blocks of trials terminated at 44 sec before the encounter point but one block of trials began at 48 sec and the other at 52 sec before encounter. If response perseverance was in effect, the incidence of error for the 52 to 44 sec block would be higher than that of the 48 to 44 sec block. In addition, there would be no significant difference between the 4- and 8-sec viewing times. In Experiment 6, evidence for the presence of response perseverance would be indicated by a significant difference between the mean error rates under each viewing time; the error rate in the trials in which

there was more time to the encounter point would be higher and the rate would decrease with shorter times to encounter. Moreover, there would be no significant differences in mean error rates between the 4- and 8-sec viewing times (see table 4).

TABLE 4.- VIEWING TIMES FOR EXPERIMENT 6.
VIEWING TIME EQUALS TON MINUS TOFF

TOFF,[a] sec	TON,[b] sec			
	60	56	52	48
52	8	4		
48		8	4	
44			8	4

[a]Time to encounter at end of trial.
[b]Time to encounter at beginning of trial.

Independent Variables

Four subjects were randomly assigned to each of two predictor display groups (straight or curved). Baseline and training began at 60 sec and ended at 44 sec before encounter, or a total viewing time of 16 sec. All experimental trials were terminated at 52, 48, or 44 sec before encounter and were presented for either 4 or 8 sec (see table 4). All other conditions were identical to those in Experiment 5.

Experimental Design

Subjects participated in a series of trials on three consecutive days. On Day 1, all subjects were trained and provided baseline data with the display format they would use for all experimental trials. On Days 1, 2, and 3, subjects made responses to all six blocks of test trials with 24 encounters per block. All subjects experienced all levels of the independent variables under one of the two types of predictor. Mean error rates were collected. Time to encounter, viewing time, and encounter sequence were randomized.

Results

Tables 5 and 6 show the mean percent error rates for each viewing time, for time to encounter point, and for each day averaged over subjects for each display type. There were 24 trials per cell per subject for a total of 96 trials. per cell.

Multiple comparisons were conducted comparing the different times to encounter point for each viewing time (4 and 8 sec) under each predictor condition for each day averaged over subjects. Of the 12 comparisons conducted, only 3 indicated the presence of a significant difference (see table 7).

TABLE 5.- PERCENT ERROR AVERAGED OVER FOUR SUBJECTS FOR THE STRAIGHT-PREDICTOR CONDITION

TOFF, sec	Day 1				Day 2				Day 3			
	TON, sec				TON, sec				TON, sec			
	60	56	52	48	60	56	52	48	60	56	52	48
52	25	29			21	22			18	23		
48		20	30			22	25			17	16	
44			27	31			13	21			19	11

TABLE 6.- PERCENT ERROR AVERAGED OVER FOUR SUBJECTS FOR THE CURVED-PREDICTOR CONDITION

TOFF, sec	Day 1				Day 2				Day 3			
	TON, sec				TON, sec				TON, sec			
	60	56	52	48	60	56	52	48	60	56	52	48
52	18	21			17	13			8	9		
48		13	11			9	8			7	6	
44			5	10			8	13			5	4

TABLE 7.- MULTIPLE COMPARISONS FOR VIEWING TIME UNDER EACH TIME TO ENCOUNTER POINT, EACH DAY, AVERAGED OVER FOUR SUBJECTS

Source	SS	df	MS	F
Straight Predictor				
8 sec/Day 1	6.00	2	3.00	2.21
error term	8.83	6	1.47	
8 sec/Day 2	12.17	2	6.09	3.48
error term	10.50	6	1.75	
8 sec/Day 3	.50	2	.25	<1
error term	26.17	6	4.36	
4 sec/Day 1	.50	2	.25	<1
error term	14.83	6	2.47	
4 sec/Day 2	2.20	2	1.10	<1
error term	28.46	6	4.75	
4 sec/Day 3	18.17	2	9.09	5.54[a]
error term	9.83	6	1.67	
Curved Predictors				
8 sec/Day 1	21.50	2	10.75	4.89
error term	13.17	6	2.19	
8 sec/Day 2	12.17	2	6.09	5.13[a]
error term	7.16	6	1.19	
8 sec/Day 3	1.17	2	.59	<1
error term	5.50	6	.92	
4 sec/Day 1	18.50	2	9.75	7.99[b]
error term	7.33	6	1.22	
4 sec/Day 2	4.17	2	2.09	1.47
error term	8.50	6	1.42	
4 sec/Day 3	3.17	2	1.59	<1
error term	10.83	6	1.89	

[a] $p < 0.05$

[b] $p < 0.025$

Consistent with the findings of Experiment 5, no significant difference was found between length of viewing time. The difference between testing days was significant, ($F(1,3) = 28.84$, $p < 0.025$). A significant difference was found for the interaction of display type and encounter type, ($F(1,3) = 11.93$, $p < 0.05$); no significant difference was found between the two types of display symbologies used or time to encounter point. All other interactions were nonsignificant (see table 8).

TABLE 8.- ANOVA USING NESTED FACTORS AND REPEATED MEASURES FOR DISPLAY (A), DAYS (B), TIME TO ENCOUNTER (C), ENCOUNTER TYPE (D), AND VIEWING TIME (E)

Source	SS	df	MS	F
A	145.92	1	145.92	4.56
B	49.01	2	24.50	7.78[a]
C	17.84	2	8.92	4.29
D	118.84	1	118.84	28.84[a]
E	3.34	1	3.34	<1
S/A	96.00	3	32.00	
AXD	49.17	1	49.17	11.93[b]
BXS/A	18.89	6	3.15	
CXS/A	12.48	6	2.08	
DXS/A	12.35	3	4.12	
EXS/A	28.60	3	9.53	

Note: Table includes main effects, significant interaction, and error terms only.
[a] $p < 0.025$
[b] $p < 0.05$

Because of the inconsistent findings concerning time to encounter point in the general ANOVA compared with previous research, further analysis was indicated. Display conditions were analyzed separately. Under straight predictor display conditions, the time to encounter remained nonsignificant, as was determined in the first analysis; however, under the curved-predictor display condition it was found to be significant, ($F(2,6) = 8.309$, $p < 0.025$). This is consistent with the results of Experiment 5 (see tables 9 and 10).

DISCUSSION

As indicated in the analysis of data for both studies, viewing time did not significantly alter the ability of subjects to accurately perceive an encounter situation. These results held constant over both types of display conditions and over times to encounter. Because of the significant difference between days of testing, it may be concluded that the ability to judge the encounter is affected more by the amount of training than by the length of the viewing time.

TABLE 9.- ANOVA, DATA FROM DISPLAY CONDITION USING CURVED PREDICTORS FOR DAYS (A), VIEWING TIME (B), AND TIME TO ENCOUNTER (C)

Source	SS	df	MS	F
A	34.19	2	17.09	12.59[a]
B	.34	1	.34	3.44
C	38.69	2	19.35	8.31[b]
S	150.82	3	50.27	
AXC	13.15	4	3.29	5.49[a]
AXS	8.14	6	1.36	
BXS	.27	3	.09	
CXS	13.97	6	2.33	
AXCXS	7.19	12	.59	

Note: Table includes main effects, significant interaction, and error items only.
[a] $p < 0.01$
[b] $p < 0.025$

TABLE 10.- ANOVA, DATA FROM DISPLAY CONDITION USING STRAIGHT PREDICTORS FOR DAYS (A), VIEWING TIME (B), AND TIME TO ENCOUNTER (C)

Source	SS	df	MS	F
A	72.33	2	36.17	7.31[a]
B	9.39	1	9.39	<1
C	5.33	2	2.67	1.45
S	41.17	3	13.72	
AXS	29.67	6	4.95	
BXS	56.94	3	18.98	
CXS	11.00	6	1.83	

Note: Table includes main effects, significant interaction, and error items only.
[a] $p < 0.025$

A question remains as to the effect of the time to encounter on accuracy of prediction. Data from Experiment 5 show a significant effect on accuracy for different times but data from Experiment 6 showed no significant difference. Further analyses of the data from Experiment 6 were conducted on the error rate for each of the two display conditions. When using straight predictors, the time to encounter remained nonsignificant although it was significant under the curved-predictor condition. These findings lend support to the findings of Experiment 5 in which the time to encounter affected performance under the curved-predictor condition. These results seem to be consistent across the two current experiments but inconsistent between display types. Information from previous experiments, in which it was noted that curved encounters using straight-predictor conditions were consistently misinterpreted (thus resulting in erroneous judgments), may be one explanation. This variability due to an interaction between encounter type and prediction type may have masked any difference due to time-to-encounter point.

Results of these two studies produced no evidence of response perseverance. There was no significant difference in performance due to viewing time or in the interaction between viewing time and the time to encounter. Analysis of error rate for different times to encounter under each viewing time indicated no consistent significant difference for either display type over the 3-day testing period.

Displays using predictors that provided turn-rate information as well as speed and distance information (curved predictors) prove to be more accurate when overall percent errors for straight (21%) and curved (10%) predictors are compared. Over the 3 days of testing, the results of both predictor types demonstrated a gradual improvement in judgment accuracy. For the straight predictors, the error rate of 27% on Day 1 and declined to 17% on Day 3. Similar results were found with the curved predictor (13% on Day 1 and 6.5% on Day 3). It was demonstrated that the type of encounter (straight or turning) had a significant effect on the ability of subjects to determine the outcome of a situation. Because they are perceptually more complex, encounters involving a turn produce a higher error rate across other variable conditions. This was consistent with the findings of prior experiments.

Previous studies have indicated that subjects exhibit a wide range of individual differences in perceptual, motivational, judgmental, and learning abilities. Statistical results from both Experiments 5 and 6 indicate that a large portion of the total variance was accounted for by individual differences.

CONCLUSION

These experiments add to a series of experiments designed to evaluate CDTI display symbology in a dynamic but controlled environment. The following are general observations based on the data from these two experiments.

1. It is more difficult to make judgments of separation at longer times before the encounter point.

2. The length of time the display was viewed did not affect judgment of the encounter.

3. The best results were obtained when both aircraft had curved predictors.

4. No evidence of response perseverance was found.

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16. Abstract

The concept of a cockpit display of traffic information (CDTI) includes the integration of air traffic, navigation, and other pertinent information in a single electronic display in the cockpit. The two studies reported here were conducted as part of a research project designed to develop a clear and concise display format for use in later full-mission simulator evaluations of the CDTI concept. Subjects were required to monitor a CDTI for specified periods of time and to make perceptual judgments concerning the future position of a single intruder aircraft in relationship to their own aircraft. Experimental variables included: type of predictor information displayed on the two aircraft symbols; time to encounter point; length of time subjects viewed the display; amount of practice; and type of encounter (straight or turning). Results show that length of viewing time had little or no effect on performance; time to encounter influenced performance with the straight predictor but did not with the curved predictor; and that learning occurred under all conditions.

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